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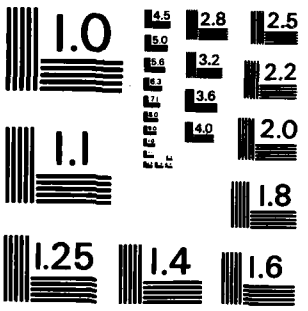

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INFLUENCE OF PARTIAL COHERENCE ON LIGHT TRANSMISSION AND ON IMAGE FORMATION

FINAL REPORT

CONTRACT No. DAAG29-80-C-0020

PREPARED BY
EMIL WOLF

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This research was primarily concerned with the broad area of optical coherence theory, with special reference to the influence of partial coherence on light transmission. Some newly discovered effects relating to focussing, as well as correction of wave-front distortions by the technique of phase conjugation were also studied; these topics are of special relevance for the understanding of the structure of images, especially those formed with laser light, and for adaptive optics.

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INFLUENCE OF PARTIAL COHERENCE ON LIGHT TRANSMISSION AND ON IMAGE FORMATION

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December 1982

Sponsored by the U.S. Army Research Office

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LIST OF CONTENTS

I. Introduction

This report contains a summary of research, performed under contract No. DAAG 29-80-C-0020, covering the period Dec. 19, 1979 - Dec. 18, 1982. Most of the research was concerned with the broad area of optical coherence theory, with special reference to the influence of partial coherence on light transmission. Some newly discovered effects relating to focussing, as well as correction of wave-front distortions by the technique of phase conjugation were also studied; these topics are of special relevance for the understanding of the structure of images, especially those formed with laser light, and for adaptive optics.

Broadly speaking, the investigations that were carried out under this contract may be divided into several groups:

(i) Transmission of partially coherent light (# 5, 6, 17, 24)*

The radiative transfer model with partially coherent light was studied and was applied to the propagation of radiation from various model sources that are believed to represent reasonably well most commonly used sources. They include the so-called quasi-homogeneous sources and Schell-model sources. A two-parameter characterization of light beams generated by Schell-model sources whose intensity distribution and degree of coherence are both Gaussian was found; it bears a close resemblance to the well-known characterization of a fully coherent Gaussian laser beam.

(ii) Space-frequency description of partially coherent light (# 3, 4, 7, 15, 25)

Partially coherent sources and partially coherent fields have been described in the past almost entirely in terms of correlation

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* The numbers refer to publications listed on pp. 5-6. Summaries of the publications are given on pp. 7 - 16.

functions of the light vibrations at different space-time points. For many purposes, particularly when dealing with narrow band light, a description in terms of correlations in the space-frequency domain is preferable, especially when the light interacts with linear media. This is so because the interaction between a linear medium and an external electromagnetic field is most simply and most naturally described by frequency-dependent response functions, such as the dielectric constant or the refractive index. Past attempts to formulate a satisfactory theory of partial coherence along these lines encountered considerable difficulties, because of the well-known fact that a stationary random process does not admit a Fourier integral representation within the framework of ordinary function theory.

The research under this contract led to a formulation of a theory of partial coherence in the space-frequency domain, using as basis not the exponential kernels of the Fourier representation, but rather the eigenfunctions of an integral equation whose kernel is the cross-spectral density of the field. The theory provides a new description of partially coherent sources and partially coherent fields in terms of spatially fully coherent modes. This model provides a novel way of analyzing problems of generation, propagation and interaction of optical fields of any state of coherence and provides new insights into phenomena that can not be readily treated by conventional methods.

(iii) The focal-shift phenomenon (#8, 9, 13, 19)

According to the classic theory of focussing, when a monochromatic, converging, spherical wave is diffracted at an aperture in an opaque screen, the point of maximum intensity of the diffracted wave is located at the geometrical focus. However, in a number of publications that have appeared in the last few years, some of which refer to focussing of laser beams,

theoretical results were reported that contradict this apparently well established fact. According to these publications, the point of maximum intensity in some focussing systems may be located between the geometrical focus and the aperture, rather than at the geometrical focus itself.

A thorough investigation of this problem was carried out under this contract and it was found that for systems focussing uniform spherical waves the classical results apply only to systems whose Fresnel numbers $N = a^2/\lambda f$ are large compared to unity. (Here a is the aperture radius, f is the focal length and λ is the wavelength.) This condition is satisfied by most conventional optical systems, but not by some of the newer systems used for focussing laser light. Numerical results were obtained which show the dependence of the focal shift and of the intensity maxima on the Fresnel number. Corresponding results pertaining to systems focussing Gaussian laser beams were also obtained. The results should prove particularly useful in connection with the design of long focal-length infrared laser systems and in evaluation of their performance, in integrated optics and for various applications that utilize laser light.

(iv) Distortion-correction by phase conjugation (#12, 16, 20, 22, 23)

Developments that took place in nonlinear optics in the last few years have made it possible to generate from a given light wave another light wave, whose phase is reversed at each point in the plane of a device known as the phase-conjugate mirror. The new wave that is generated by this process is called the phase-conjugate wave.

One of the main applications envisioned for the technique of phase conjugation is to the correction of distortions that are imparted on a light wave by its interaction with a scattering medium. Although a number of experiments have been carried out that demonstrate the possibility of

improving the quality of an image by this method, no satisfactory theory exists at the present time that is applicable to all the experimental situations described in the literature or envisioned for future applications, especially in adaptive optics.

The investigations in this area that were performed under this contract aimed at providing a satisfactory theory from which the degree of correction that may be achieved by optical phase conjugation could be determined. An integral equation was formulated for scattering of light waves in the presence of a phase-conjugate mirror. The solution of this equation was analyzed for a number of situations, particularly those involving weak scatterers. It was also shown that if the scatterer is non-absorbing and the conjugate wave is generated without losses or gains, complete cancellation of the distortions may be obtained.

Because of the complexity of the physical processes involved in this technique, much further work remains to be done in this area, but it is believed that the integral equation derived by us will provide the basis for further studies of distortion-corrections by phase conjugation.

II. LIST OF PUBLICATIONS

1. E. COLLETT and E. WOLF: "Symmetry Properties of Focused Fields" [Opt. Lett., 5, 264-266 (1980)].*

2. E. WOLF: "Phase Conjugacy and Symmetries in Spatially Bandlimited Wavefields Containing No Evanescent Components" [J. Opt. Soc. Amer., 70, 1311-1319 (1980)].

3. L. MANDEL and E. WOLF: "Complete Coherence in the Space-Frequency Domain" [Opt. Commun., 36, 247-249 (1981)].

4. E. WOLF: "A New Description of Second-Order Coherence Phenomena in the Space-Frequency Domain" [Optics in Four Dimensions-1980 (ICO, Ensenada), M.A. Machado and L. M. Narducci, eds. (Conference Proceedings #65, American Institute of Physics, New York, 1981), pp. 42-48].

5. A. T. FRIBERG: "Phase-Space Methods for Partially Coherent Wavefields" [Optics in Four Dimensions-1980 (ICO, Ensenada), M. A. Machado and L. M. Narducci, eds. (Conference Proceedings #65, American Institute of Physics, New York, 1981), pp. 313-331].†

6. ARI T. FRIBERG: "On the Generalized Radiance Associated With Radiation From a Quasihomogeneous Planar Source" [Opt. Acta, 28, 261-277 (1981)].*†

7. E. WOLF: "New Spectral Representation of Random Sources and of the Partially Coherent Fields That They Generate" [Opt. Commun., 38, 3-6 (1981)].

8. E. WOLF and YAJUN LI: "Conditions For the Validity of the Debye Integral Representation of Focused Fields" [Opt. Commun., 39, 205-210 (1981)].

9. YAJUN LI and E. WOLF: "Focal Shifts in Diffracted Converging Spherical Waves" [Opt. Commun., 39, 211-215 (1981)].

10. YAJUN LI: "Method of Successive Approximations For Calculating the Eigenvalues of Optical Thin-Film Waveguides" [Appl. Opt., 20, 2595-2597 (1981)].

11. E. WOLF: "New Theory of Partial Coherence in the Space-Frequency Domain. Part I: Spectra and Cross-Spectra of Steady-State Sources" [J. Opt. Soc. Amer., 72, 343-351 (1982)].

12. G. S. AGARWAL and E. WOLF: "Theory of Phase Conjugation With Weak Scatterers" [J. Opt. Soc. Amer., 72, 321-326 (1982)].

13. YAJUN LI: "Dependence of the Focal Shift on the Fresnel Number and f-Number" [J. Opt. Soc. Amer., 72, 770-774 (1982)].

II. PUBLICATIONS (cont'd)

14. YAJUN LI and E. WOLF: "Radiation from Anisotropic Gaussian Schell-Model Sources" [Opt. Lett., 7, 256-258 (1982)].

15. A. STARIKOV and E. WOLF: "Coherent-Mode Representation of Gaussian Schell-Model Sources and of Their Radiation Fields" [J. Opt. Soc. Amer., 72, 923-928 (1982)].

16. G.S. AGARWAL, A.T. FRIBERG and E. WOLF: "Effect of Back-scattering in Phase Conjugation with Weak Scatterers" [J. Opt. Soc. Amer., 72, 861-863 (1982)].

17. A.T. FRIBERG and RONALD J. SUDOL: "Propagation Parameters of Gaussian Schell-Model Beams" [Opt. Commun., 41, 383-387 (1982)].

18. G.S. AGARWAL and SURENDRA SINGH: "Effect of Pump Fluctuations on Lineshapes in Coherent Anti-Stokes Raman Scattering" [Phys. Rev. A 25, 3195-3205 (1982)].††

19. YAJUN LI and E. WOLF: "Focal Shift in Focused Truncated Gaussian Beams" [Opt. Commun., 42, 151-156 (1982)].

20. G.S. AGARWAL, ARI T. FRIBERG and E. WOLF: "Elimination of Distortions by Phase Conjugation without Losses or Gains" [Opt. Commun., 43, 446-450 (1982)].

21. ARI T. FRIBERG and E. WOLF: "Angular Spectrum Representation of Scattered Electromagnetic Fields" [J. Opt. Soc. Amer., in press].

22. ARI T. FRIBERG: "On the Integral Equation of the Scattered Field in the Presence of a Phase-Conjugate Mirror" [J. Opt. Soc. Amer., in press].

23. G.S. AGARWAL, ARI T. FRIBERG and E. WOLF: "Scattering Theory of Distortion-Correction by Phase Conjugation" [J. Opt. Soc. Amer., in press].

24. ARI T. FRIBERG and RONALD J. SUDOL: "The Spatial Coherence Properties of Gaussian Schell-Model Beams" [Opt. Acta, submitted].

25. A. STARIKOV: "Effective Number of Degrees of Freedom of Partially Coherent Sources" [J. Opt. Soc. Amer., 72, 1538-1544 (1982)].

*Work supported in part by the U.S. Army Electronics Command.

†Work sup orted in part by the Academy of Finland.

††Work supported in part by the Air Force Office of Scientific Research.

III. SUMMARIES OF PUBLICATIONS:

1. E. COLLETT and E. WOLF

SYMMETRY PROPERTIES OF FOCUSED FIELDS

OPT. LETT. 5, 264-266 (1980)

It is shown that under very general conditions monochromatic scalar wave fields that have a focus in the sense of geometrical optics possess some simple symmetry properties with respect to the focus. Certain well-known but poorly understood symmetry properties of the three-dimensional amplitude distribution and phase distribution in the focal region of a uniform converging spherical wave diffracted at a circular aperture are found to be immediate consequences of our results.

2. E. WOLF

PHASE CONJUGACY AND SYMMETRIES IN SPATIALLY BANDLIMITED WAVEFIELDS CONTAINING NO EVANESCENT COMPONENTS

J. OPT. SOC. AMER., 70, 1311-1319 (1980)

Several theorems are formulated, regarding symmetry relations between two monochromatic fields that propagate either into the same half-space ($z>0$) or into two complementary half-spaces ($z>0$ and $z<0$) and that satisfy one of two simple phase-conjugacy conditions in a cross sectional plane z=constant. The theorems are rigorously valid for fields whose two-dimensional spatial-frequency spectrum in the cross-sectional plane is bandlimited to a circle of radius equal to the wave number of the field. One of the theorems elucidates some recently predicted symmetry properties of focused fields.

3. L. MANDEL and E. WOLF

COMPLETE COHERENCE IN THE SPACE-FREQUENCY DOMAIN

OPT. COMMUN., 36, 247-249 (1981)

An expression is derived for the general form of the cross-spectral density of a field that is spatially fully coherent, throughout some region of space, at some particular temporal frequency.

III. SUMMARIES (cont'd)

4. E. WOLF

A NEW DESCRIPTION OF SECOND-ORDER COHERENCE PHENOMENA IN THE SPACE-FREQUENCY DOMAIN

OPTICS IN FOUR DIMENSIONS-1980 (ICO, ENSENADA),
M.A. MACHADO and L.M. NARDUCCI, EDS.
(CONFERENCE PROCEEDINGS #65, AMERICAN INSTITUTE OF PHYSICS, NEW YORK, 1981)
pp. 42-48

A new representation is obtained for the cross-spectral density function of stationary optical wavefields. We show that under very general conditions it is possible to construct an ensemble of monochromatic wave functions, all of the same frequency ω, with the property that the cross-spectral density function $W(\underline{r}_1,\underline{r}_2,\omega)$ of the field is expressible as a correlation between the values of the wave functions at the points $\underline{r}_1$ and $\underline{r}_2$. The representation is intimately related to a new mode expansion of the field and has a number of potential applications to various problems that involve wavefields of any state of coherence.

5. A. T. FRIBERG

PHASE-SPACE METHODS FOR PARTIALLY COHERENT WAVEFIELDS

OPTICS IN FOUR DIMENSIONS-1980 (ICO, ENSENADA),
M.A. MACHADO and L.M. NARDUCCI, EDS.
(CONFERENCE PROCEEDINGS #65, AMERICAN INSTITUTE OF PHYSICS, NEW YORK, 1981)
pp. 313-331

As is well known, the expectation value of a quantum mechanical operator may be expressed in a form of a classical c-number average with respect to the so-called generalized phase-space distribution functions. The observable quantities in the theory of radiometry with partially coherent light may be represented as appropriate integral transforms of the so-called generalized radiance functions that bear some formal resemblance to such distribution functions. In the present paper, we consider analogies between various quantum mechanical phase-space distribution functions and generalized radiance functions associated with an optical wavefield of any state of coherence. Some misconceptions surrounding the implications of the possible negativeness of the generalized radiance are discussed. Several unsolved problems in the area of generalized radiometry with partially coherent wavefields are also mentioned.

III. SUMMARIES (cont'd)

6. A. T. FRIBERG

ON THE GENERALIZED RADIANCE ASSOCIATED WITH RADIATION FROM A QUASIHOMOGENEOUS PLANAR SOURCE

OPT. ACTA, 28, 261-277 (1981)

The properties of the (generalized) radiance associated with a quasi-homogeneous planar source and with the optical field it generates are discussed. In the source plane the radiance is found to satisfy the usual postulates of conventional radiometry. An estimate is obtained for the distance along a straight line over which the radiance remains substantially unchanged. If the source is strictly homogeneous or if the field is treated in the paraxial approximation, the radiance is shown to obey the conventional propagation law exactly.

7. E. WOLF

NEW SPECTRAL REPRESENTATION OF RANDOM SOURCES AND OF THE PARTIALLY COHERENT FIELDS THAT THEY GENERATE

OPT. COMMUN., 38, 3-6 (1981)

It is shown that, contrary to general belief, it is possible to construct a statistical ensemble of monochromatic oscillations, all of the same frequency, that yields rigorously the spectral and cross-spectral densities of a fluctuating, statistically stationary source and of the field that the source generates. New mode representations are also introduced. The modes may be interpreted as natural oscillations of sources and fields of any state of coherence.

8. E. WOLF and YAJUN LI

CONDITIONS FOR THE VALIDITY OF THE DEBYE INTEGRAL REPRESENTATION OF FOCUSED FIELDS

OPT. COMMUN., 39, 205-210 (1981)

A very simple sufficiency condition is obtained, under which the Debye diffraction integral may be expected to give a good approximation to the solution of a boundary value problem that is generally taken to represent a field in the region of focus. When the angular aperture of the focusing system is sufficiently small, the condition reduces to the requirement that the Fresnel number of the diffracting aperture, when viewed from the geometrical focus, is large compared to unity.

III. SUMMARIES (con't)

9. YAJUN LI and E. WOLF

FOCAL SHIFTS IN DIFFRACTED CONVERGING SPHERICAL WAVES

OPT. COMM., 39, 211-215 (1981)

It is known from a number of publications that when a converging, monochromatic spherical wave is diffracted at a circular aperture, the point of maximum intensity of the diffracted wave may not be at the geometrical focus of the incident wave, but may be located closer to the aperture. In the present note we show that when the incident wave is uniform and the angular semi-aperture is small, the ratio of such a shift Δf of the point of maximum intensity to the distance f between the geometrical focus and the plane of the aperture depends only on the Fresnel number N of the aperture when viewed from the geometrical focus. The effect becomes significant when $N \lesssim 5$. When $N=1$, for example, $|\Delta f| \simeq 0.4f$ and the maximum intensity is approximately twice as large as the intensity at the geometrical focus.

10. YAJUN LI

METHOD OF SUCCESSIVE APPROXIMATIONS FOR CALCULATING THE EIGENVALUES OF OPTICAL THIN-FILM WAVEGUIDES

APPL. OPT., 20, 2595-2597 (1981)

A formula of successive approximations for calculating the eigenvalues of optical thin-film waveguides is proposed. On the basis of this formula, an unified explicit solution is obtained, which has the same form for both TE and TM modes. Changing one of the parameters of the approximate formula, we obtain lower and upper bounds of the eigenvalues, thus making it possible to estimate its range of validity.

11. E. WOLF

NEW THEORY OF PARTIAL COHERENCE IN THE SPACE-FREQUENCY DOMAIN PART I: SPECTRA AND CROSS-SPECTRA OF STEADY-STATE SOURCES

J. OPT. SOC. AMER., 72, 343-351 (1982)

It is shown that, under very general conditions, the cross-spectral density of a steady-state source of any state of coherence may be expressed in terms of certain new modes of oscillations, each of which represents a completely spatially coherent elementary excitation. Making use of this result, a statistical ensemble of strictly monochromatic oscillations, all of the same temporal frequency, is then introduced that yields the cross-spectral density as a correlation function in the space-frequency domain. From these results two new expressions for the Wiener-Khintchine

III. SUMMARIES (cont'd)

spectrum of the source and also a new mode representation of the cross-correlation function of the source follow at once.

12. G. S. AGARWAL and E. WOLF

THEORY OF PHASE CONJUGATION WITH WEAK SCATTERERS

J. OPT. SOC. AMER., 72, 321-326 (1982)

A theory relating to correction of distortions that may be achieved by phase conjugation is developed on the basis of the first Born approximation. It is shown that, to good accuracy, the effect of a distorting medium on an incident wave is eliminated by phase conjugation if the following conditions are satisfied: the incident field contains no evanescent components, the transmitting medium is a weak, nonabsorbing scatterer, and backscattering of the incident and of the conjugate wave and also the effects of scattered evanescent waves are negligible.

13. YAJUN LI

DEPENDENCE OF THE FOCAL SHIFT ON THE FRESNEL NUMBER AND f-NUMBER

J. OPT. SOC. AMER., 72, 770-774 (1982)

The behavior of the intensity along the axis, arising from the diffraction of a uniform, converging spherical wave at a circular aperture is studied on the basis of the theory of the boundary diffraction wave. The results are used to determine the location of the principal intensity maximum and to elucidate the dependence of the focal shift both on the Fresnel number and on the f-number of the focusing geometry. Analytic, as well as numerical, results are obtained. Comparison with microwave experiments of Farnell [Can. J. Phys., 36, 935 (1958)] is also made.

14. YAJUN LI and E. WOLF

RADIATION FROM ANISOTROPIC GAUSSIAN SCHELL-MODEL SOURCES

OPT. LETT., 7, 256-258 (1982)

Expressions are derived for the radiant intensity generated by a planar, anisotropic, Gaussian, Schell-model source of any state of coherence. It is found that with an appropriate choice of the source parameters the

III. SUMMARIES (cont'd)

radiant intensity may be rotationally symmetric about the source plane and may even become identical with the radiant intensity produced by a completely coherent and rotationally symmetric laser source.

15. A. STARIKOV and E. WOLF

COHERENT-MODE REPRESENTATION OF GAUSSIAN SCHELL-MODEL SOURCES AND OF THEIR RADIATION FIELDS

J. OPT. SOC. AMER., 72, 923-928 (1982)

A recently formulated theory of partial coherence in the space-frequency domain is used to determine the mode structure of an important class of partially coherent sources and of the radiation fields generated by them. The effective number of modes is found to depend in a fundamental way on the ratio of the coherence length to the effective size of the source. The contribution of the effective modes to the far-field intensity is also analyzed.

16. G. S. AGARWAL, A. T. FRIBERG and E. WOLF

EFFECT OF BACK-SCATTERING IN PHASE CONJUGATION WITH WEAK SCATTERERS

J. OPT. SOC. AMER., 72, 861-863 (1982)

An extension is presented of a recently developed theory (based on the first Born approximation) of cancellation of distortions by phase conjugation. The influence of back-scattering of both the incident and the conjugate waves is considered. It is shown that, when back-scattering is taken into account, distortions are not eliminated by phase conjugation, except when the conjugate wave is generated without a loss or a gain.

III. SUMMARIES (cont'd)

17. A. T. FRIBERG and RONALD J. SUDOL

PROPAGATION PARAMETERS OF GAUSSIAN SCHELL-MODEL BEAMS

OPT. COMMUN., 41, 383-387 (1982)

The propagation of partially coherent light beams generated by Gaussian Schell-model sources is found to be conveniently characterized by two parameters that are analogous to the beam radius and the radius of wavefront curvature of fully coherent Gaussian laser beams. Gaussian quasi-homogeneous beams are examined as a limiting case.

18. G. S. AGARWAL and SURENDRA SINGH

EFFECT OF PUMP FLUCTUATIONS ON LINESHAPES IN COHERENT ANTI-STOKES RAMAN SCATTERING

PHYS. REV. A, 25, 3195-3205 (1982)

The theory of coherent anti-Stokes Raman scattering (CARS) is extended to include the effect of pump fluctuations. The intensities and spectra of lines in resonant CARS are calculated to all orders in fields assuming phase diffusion model for waves at the two pump frequencies. The bandwidth of the two lasers enters in a much more complicated way than following a simple scaling of T_1 or T_2. Various resonances in CARS spectra due to dynamic splitting of the energy levels are discussed for a range of detunings, field intensities and bandwidths. In contrast to the usual spectra in strong fields, the Rabi sidebands appear as dispersion shaped structures. The laser linewidth is shown to change dramatically the CARS lineshape. The case of no-saturation is also treated, thus allowing for the inclusion of more general lineshapes and fluctuations of the pump waves and the nonlinear susceptibility tensor $\chi^{(3)}$. Gaussian statistics of the pump field are shown to lead to enhancement factors in CARS intensity, similar to those appearing in the context of multiphoton absorption processes.

19. YAJUN LI and E. WOLF

FOCAL SHIFT IN FOCUSED TRUNCATED GAUSSIAN BEAMS

OPT. COMMUN., 42, 151-156 (1982)

It is known that under certain circumstances the point of maximum intensity in a focused aberration-free wave is not at the geometrical focus, but is closer to the focusing lens. In the present note such a focal shift is analyzed for the case of a Gaussian beam, focused by a thin lens which

III. SUMMARIES (cont'd)

fills a circular aperture of any prescribed radius, the waist of the beam being assumed to be located in the aperture plane. Many previously known results follow as limiting cases of our analysis.

20. G.S. AGARWAL, ARI T. FRIBERG and E. WOLF

ELIMINATION OF DISTORTIONS BY PHASE CONJUGATION WITHOUT LOSSES OR GAINS

OPT. COMMUN., 43, 446-450 (1982)

It is shown on the basis of scalar wave theory that complete cancellation of distortion effects by the technique of phase conjugation will be achieved under the following circumstances: The scatterer is non-absorbing, the conjugate wave is generated without losses or gains at an infinite phase-conjugate mirror and the effects of the evanescent waves outside the scatterer are negligible. The analysis is carried out to all orders of perturbation theory and is based on a new integral-equation formulation that involves a Green's function which takes into account the presence of the phase-conjugate mirror.

21. ARI T. FRIBERG and E. WOLF

ANGULAR SPECTRUM REPRESENTATION OF SCATTERED ELECTROMAGNETIC FIELDS

J. OPT. SOC. AMER., in press

Angular spectrum representation is derived for the electromagnetic field scattered from any linear, time-independent medium. In particular, the medium may be homogeneous or inhomogeneous, isotropic or anisotropic, spatially non-dispersive or spatially dispersive and it may be dielectric, magnetic or magneto-electric. The spectral amplitudes of the plane-wave modes of the scattered field are found to depend in a relatively simple manner on the induced polarization and on the induced magnetization. In the special case when the first Born approximation applies, the results take a particularly simple form and may be used to determine the scattered electromagnetic field vectors at any distance from the scatterer.

III. SUMMARIES (cont'd)

22. ARI T. FRIBERG

ON THE INTEGRAL EQUATION OF THE SCATTERED FIELD IN THE PRESENCE OF A PHASE-CONJUGATE MIRROR

J. OPT. SOC. AMER., in press

A conceptually simple derivation is given for the basic integral equation of the scattered field in the presence of an infinite phase-conjugate mirror. This integral equation is exact, except for the fact that the incident field is assumed to contain no evanescent components and the effects of the evanescent waves are neglected at the phase-conjugate mirror.

23. G.S. AGARWAL, ARI T. FRIBERG and E. WOLF

SCATTERING THEORY OF DISTORTION-CORRECTION BY PHASE CONJUGATION

J. OPT. SOC. AMER., in press

The correction of wave distortions by the technique of optical phase conjugation is examined first on the basis of a newly derived integral equation for scattering of monochromatic scalar waves in the presence of a phase-conjugate mirror. The solution is developed in an iterative series, and the first- and second-order terms are analyzed and illustrated diagrammatically. A generalization of the integral equation is presented, which takes into account the electromagnetic nature of light. It is also shown that if the conjugated wave is generated without losses or gains and with a complete reversal of polarization, a total elimination of distortions may be achieved by this technique under circumstances that frequently occur in practice.

24. ARI T. FRIBERG and RONALD J. SUDOL

THE SPATIAL COHERENCE PROPERTIES OF GAUSSIAN SCHELL-MODEL BEAMS

OPT. ACTA, submitted

The transverse and longitudinal spatial coherence properties of the the light beams generated by planar Gaussian Schell-model sources are discussed. It is found that for all Gaussian Schell-model beams the ratio of the transverse coherence length to the beam width remains invariant upon propagation. An examination of the longitudinal coherence for both on-axis and off-axis pairs of points indicates that the longitudinal coherence will not, in general, die out as the separation between

III. SUMMARIES (cont'd)

the points is increased. Rather, the degree of longitudinal coherence will approach a finite (non-zero) value as long as the source contains a finite coherence area, regardless of how small this area may be. Gaussian quasi-homogeneous beams are studied as a limiting case. The relation of the present work to the analysis of speckle size is briefly discussed.

25. A. STARIKOV

EFFECTIVE NUMBER OF DEGREES OF FREEDOM OF PARTIALLY COHERENT SOURCES

J. OPT. SOC. AMER., 72, 1538-1544 (1982)

Orthogonal expansion of a partially coherent source with a given cross-spectral density W is used to define an effective number N of degrees of freedom and an effective number $\mathcal{N}$ of uncorrelated random variables characterizing the source. Relations $\mathcal{N} \leq N \equiv \mathrm{Tr}\, W/\lambda_0 \leq (\mathrm{Tr}\, W/\|W\|)^2 = V_e/V_{ce}$ are established and discussed. Here Tr W, $\|W\|$, and λ_0 are, respectively, the trace, the norm, and the largest eigenvalue of W used as the kernel of a homogeneous Fredholm equation; V_e is an effective volume of the source; and V_{ce} is its effective coherence volume. The main results are illustrated by a Gaussian Schell-model source.

IV. ADVANCED DEGREE EARNED BY A GRADUATE RESEARCH ASSISTANT WHILE EMPLOYED ON THIS PROJECT

ARI T. FRIBERG, Ph.D. Degree, University of Rochester (1980)

Title of Thesis: "Radiometry with Partially Coherent Light".

V. LIST OF SCIENTIFIC PERSONNEL

The following persons assisted in the research under this Grant:

E. WOLF, Professor of Physics, Principal Investigator

ARI T. FRIBERG, Research Associate (7/80-10/80); Research Associate and Visiting Assistant Professor (9/81-12/82)

Y. LI, Visiting Research Associate, Part-Time

G. S. AGARWAL, Visiting Scientist

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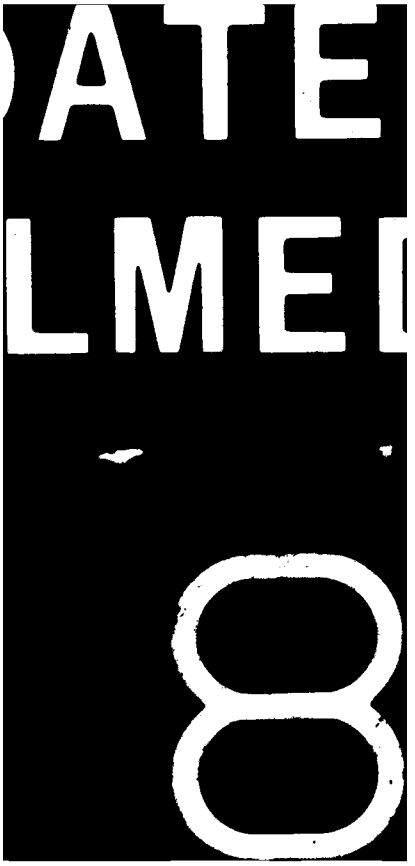
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